

## REACTION TIMES OF PIGEONS ON A WAVELENGTH DISCRIMINATION TASK

DONALD S. BLOUGH<sup>1</sup>

BROWN UNIVERSITY

After extensive pretraining, three pigeons were exposed in 2-second trials to a random series of 14 light wavelengths, ranging in one nanometer (nm) steps from 575 nanometers to 589 nanometers. Responses to one of the wavelengths, 582 nanometers, were intermittently reinforced. The relative frequency of response approached 1.0 at 582 nanometers, and decreased with progressively higher and lower wavelengths. Reaction times shorter than about 0.2 second occurred with a low frequency that was largely independent of wavelength. Wavelength controlled the frequency of longer reaction times, but did not affect the distribution of these reaction times. Consequently, receiver-operating characteristic curves constructed by using reaction time as a rating measure did not conform to the signal-detection model, in contrast to such conformity when response rate is used in a similar way. The data suggest that stimulus onset as such triggers early response emission with some small probability; the probability of responses with longer latency is controlled by wavelength, but their time of emission is controlled by some independent process.

*Key words:* reaction time, latency, ROC curves, wavelength, discrimination, stimulus control, key peck, pigeons

A number of studies have employed signal-detection procedures in animal experiments (*e.g.*, Blough, 1967; Heinemann, Avin, Sullivan, and Chase, 1969; Wright, 1972). Among these are a few studies that used the "rating" method to generate receiver-operating characteristic curves (Green and Swets, 1966). For example, Blough (1967) used the number of key pecks emitted during a 30-sec stimulus presentation as an analogue to a human's rating of confidence that a reinforced stimulus was being presented. Yager and Duncan (1971) used the latency of a fish's response to a lighted target in a similar way.

To be used as a rating, a response measure must vary systematically with the stimulus difference. Whether it so varies, and in what way, can provide insight into the nature of the processes controlling the response. In the present experiments, reaction time proved invariant with stimulus wavelength, thus limiting the sort of process that might be controlling responses in this instance.

### METHOD

#### *Subjects*

Three male White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights by supplementary feeding,

if necessary, after each experimental session. They were studied daily for approximately 2 hr, and received most of their food (mixed grain) in the experimental sessions.

#### *Apparatus*

The birds worked simultaneously in three Lehigh Valley pigeon chambers. The stimulus was a fuzzy spot of monochromatic light approximately 0.9 cm in diameter, projected on the rear of a standard translucent pigeon key. Further technical specifications of the stimulus may be found in a previous report (Blough, 1972, p. 347). The key operated on application of about 0.1 N force. Each box was ventilated by a fan and supplied with white masking noise. A LINC computer controlled the stepping motor that adjusted stimulus wavelength, together with shutters and the food magazine solenoid. The computer also recorded responses and latencies.

#### *Procedure*

The birds began the experiment after several hundred hours of training on the required

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discrimination: responses to 582 nm (S+) had been reinforced, while responses to a series of nearby wavelengths went unreinforced. This prior training followed the procedure described by Blough (1967) with minor variations; it was similar to that described below except that stimuli were presented for longer periods (30 sec). Experienced birds were used to assure that the discriminative performance would approximate a stable asymptote.

The birds worked daily in sessions consisting of 90 blocks of 16 trials each. Fourteen stimulus wavelengths appeared in each block; these ranged from 575 nm to 589 nm in 1-nm steps, and they appeared once each in random order, except that the S+, 582 nm, appeared on two extra trials per block. On most trials, pecks simply turned off the stimulus. However, on a randomly selected one of the three 582-nm presentations, pecks produced access to food for 2.5 sec.

Since the same monochromator supplied stimuli for all three birds, trial onset was synchronized across birds. At intervals ranging randomly from 4 to 5.8 sec, in 5-msec steps, the computer turned on a preselected stimulus wavelength in all three boxes. This stimulus remained on the key of each box until a peck occurred on that key, or for a maximum of 2 sec. Then, a new wavelength was selected and the next trial began at its appointed time. However, if any bird pecked its key when the stimulus was off, an interval randomly chosen from 5-msec steps between 0 and 1.8 sec was added to the interstimulus interval. Such interstimulus responses were relatively rare. The houselight, shielded so that it did not directly illuminate the response key, remained on except during reinforcement.

Response latency from stimulus onset to response on each trial was recorded in 0.02-sec bins. The birds were tested for 44 sessions; the last 88 of the 90 stimulus blocks per day from the last 20 sessions were included in the data analysis.

## RESULTS AND DISCUSSION

The results of this experiment concern data combined across the final 20 sessions of the experiment; thus, stability over this period is important to their interpretation. To check stability, three daily indices of performance were taken: (1) total responses to S+, (2) me-

dian reaction time to S+, and (3) a discrimination ratio based on S+ (582 nm) and two stimuli four steps away (578 and 586 nm). The discrimination index was the average of the responses to the two S- stimuli divided by the responses to one of the S+ stimuli randomly selected from each trial block. Trends were sought through a comparison of these measures averaged over the first six and last six days of the testing period. For all birds, S+ was responded to on at least 94% of the trials in these periods, and this percentage changes less than 3% for any bird. For all birds, the mean median reaction time to S+ lay between 300 and 390 msec in both the early and late periods, and this figure changed less than 35 msec for any bird. None of these changes approached statistical significance. For Birds 1 and 2, discrimination improved slightly but significantly across the testing period, the index going from 0.54 to 0.44 for Bird 1 ( $t = 2.1$ ,  $df = 10$ ,  $P < 0.05$ ) and from 0.53 to 0.41 for Bird 2 ( $t = 4.9$ ,  $df = 10$ ,  $P < 0.001$ ). The discrimination of Bird 3 became slightly but nonsignificantly worse across the testing period. Overall, the small changes in the behavioral indices between early and late samples of the testing period suggest that the data may safely be combined across all sessions, and this was done for the remainder of the analysis.

All birds gave regular discrimination functions centered at the 582-nm S+, such as those for Bird 1 in Figure 1. The upper curve in this figure shows the overall probability (rela-

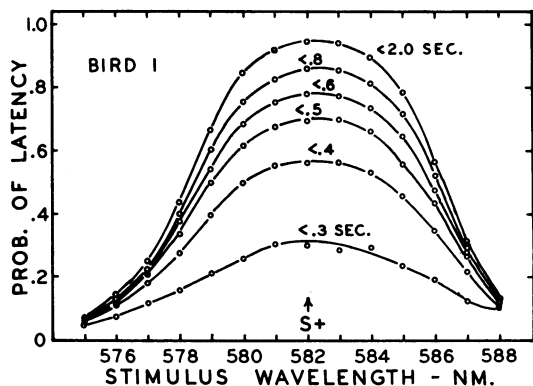


Fig. 1. Response gradients around the reinforced stimulus, 582 nm, separated according to latency. The curves for the other two birds were similar, except that the curves for Bird 3 converged on a higher asymptote, as shown in a different form in Figure 2.

tive frequency) of a response during the entire 2-sec stimulus period. This probability is near 1 at the S+ and falls systematically with increasing wavelength difference from the S+. Figure 1 also shows the probability with which responses occurred in various intervals shorter than 2 sec; the cutoff times are indicated next to the curves. These curves are similar. Their form suggests that each wavelength step away from S+ simply reduces the number of responses in each reaction-time bin by a fixed proportion, except that the curves approach a common value slightly above zero.

The interaction of stimulus control and reaction time (latency) is clearer in Figure 2. Here, the response measure is the probability with which a latency exceeded a value specified by the parameter "i". The curve for each wavelength indicates how reaction times to that wavelength relate to reaction times to the S+. Since "no response" is counted as a latency exceeding 2 sec, failure to respond to any test stimulus tends to raise its curve above the main diagonal. For clarity, only curves for wavelengths shorter than S+ are shown.

The form of the functions in Figure 2 may reflect the processes that control latency. A point falling on the main diagonal implies that the probability of exceeding the specified latency is the same as for S+. The upper-right corner of the graphs in Figure 2 shows such points on or near the diagonal. These points show that wavelength does not control short-latency responses. Though all three birds sometimes emit such wavelength-independent responses, they are most striking in Bird 3.

As latency increases, the curves depart from the diagonal, but their linearity is striking. Responses to each wavelength are an approximately fixed proportion of responses to S+ in a given reaction-time bin. In short, if an animal responds at all to a test wavelength, it responds no more slowly than to S+.

The data in Figure 2 are plotted on coordinates appropriate to signal-detection receiver-operating characteristic (ROC) functions, with latency a measure "rating" the departure of a stimulus from S+. However, the curves clearly fail to conform to the detection paradigm, which assumes that the rating will shift with stimulus value, rather than showing the independence just commented on. This result contrasts with a comparable one in which response rate, rather than latency, is used as a

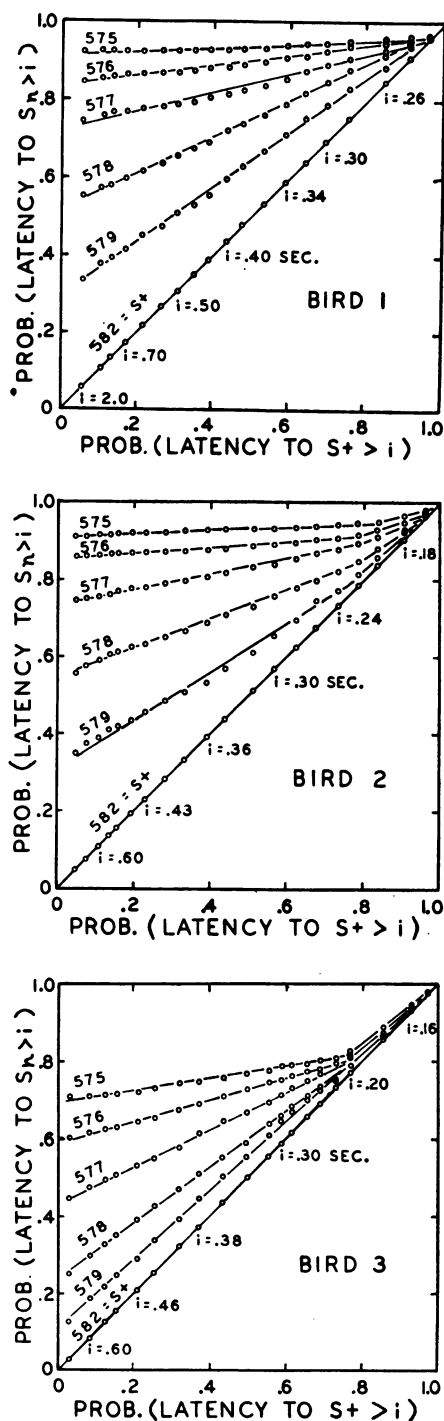


Fig. 2. Response latencies for each bird plotted in the form of signal-detection "receiver-operating characteristics". Note that responses with latency shorter than about 0.2 sec appear relatively invariant with wavelength, while longer latencies are proportional across wavelengths.

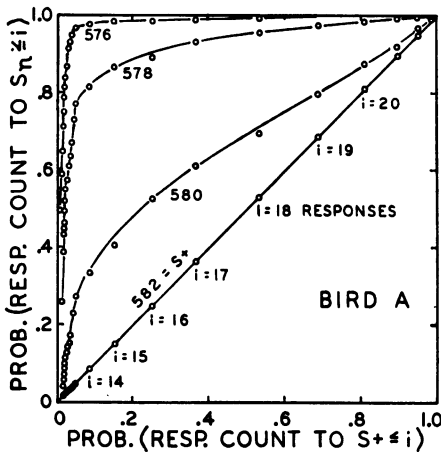


Fig. 3. Receiver-operating characteristic curves based on a rate measure rather than latency. Note the curvature, which conforms to expectations of signal-detection theory. Data from Blough (1967).

measure. Figure 3 shows data replotted from such a study (Blough, 1967). Here, the parameter "i" indicates the number of responses emitted during a 30-sec trial. This measure is not simply proportional across wavelength, and, as shown in the previous report, the curves assume the form predicted by detection theory.

The crucial aspects of the present data are seen most directly, if less analytically, in the raw latency distributions presented in Figure 4. Shading has been used to emphasize the two seemingly separable sorts of stimulus control already mentioned. For this bird, there is a peak of response latency just below 0.2 sec. These responses are controlled by the stimulus, in that they are triggered by stimulus onset, but they are not controlled by wavelength, for their frequency is almost constant across the wavelength range. This short-latency mode is followed by a second mode, peaking at about 0.35 sec. These responses clearly are controlled by wavelength, since there are many more at S+ than at the more-distant test stimuli. However, the latency distribution does not shift with wavelength; the birds do not respond more slowly when confronted by S- than when confronted by S+. It appears that the processes that control whether or not a response is to be emitted are independent of those that control the latency of the emitted responses.

Such data are by no means unprecedented in reaction-time studies with humans. Short-

latency responses not under stimulus control are not uncommon (e.g., Swensson, 1972) and, especially in situations that stress response speed, relatively invariant latency distributions of responses under stimulus control have also been reported. Ollman (1966) proposed a Fast Guess model that seems to handle these sorts of results well. According to this model, choice reaction times fall into two classes: guesses, not under stimulus control, and stimulus-controlled responses. The probability of stimulus-controlled responses may vary with the stimulus, but their reaction-time distribution is fixed. Mulvanny (1976) discussed the application of the Fast Guess model to extensive pigeon reaction-time data. He imposed a reaction-time deadline on pigeons that were performing a wavelength discrimination. Although a short deadline speeded responding, and, if short enough, increased errors considerably, the latency distributions to S+ and S- retained the same form, as in the present study. Mulvanny concluded that his data support the Fast Guess model.

The finding that latency of stimulus-controlled responses does not vary with stimulus value might seem incompatible with other data from animals in which latency does change. However, there are differences in procedure that suggest little conflict among existing results. Probably most important is the nature of the stimulus continuum. Many data indicate that response latency varies with the intensity of a visual or auditory stimulus. For example, Yager and Duncan (1971) used the intensity-latency relation to construct ROC curves for visual stimuli in goldfish; the intensity-latency relation has also been used for sensory scaling in several species (Moody, 1970). The difference between intensive ("prothetic") and qualitative ("metathetic") continua is well established in human psychophysics (Stevens, 1975), and may be expected to apply with animals as well.

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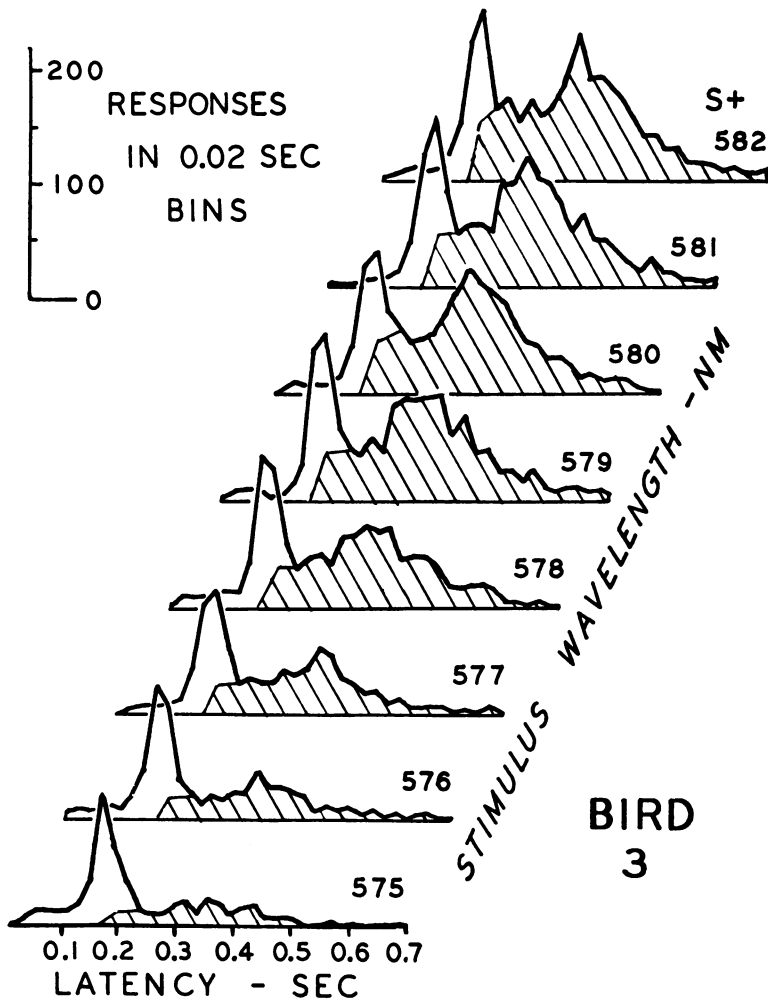


Fig. 4. Latency of responses to the S+, 582 nm, and to lower test wavelengths, for Bird 3. Shading suggests the distribution of responses that is controlled by wavelength. The latency peak at about 0.17 sec is composed of responses that are triggered by stimulus onset, but are unaffected by wavelength.

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